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Islands of lichen diversity in urban environments: a hidden richness in botanical gardens

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Abstract

Botanical gardens in city centres are green islands, offering a sanctuary for diverse plant and fungal species amidst urban landscapes. Although lichens are not usually a primary focus in botanical gardens, these spaces can serve as important refuges. In this work, the epiphytic lichen biota has been investigated in the Botanic Garden of Pisa, to uncover the hidden elements of biodiversity of botanical gardens in terms of non-target organisms. A total of 57 epiphytic lichen taxa and one non-lichenized fungus were recorded, including several threatened species. Two species, *Arthopyrenia platypyrenia* and *Coenogonium tavaresianum*, are new records for Tuscany, while *Lecania cyrtellina* is so far known in the region as occurring only in the Botanic Garden of Pisa. Lichen colonization reflects the richness of tree species, while the diffused presence of nitrogen-tolerant lichens could be associated with urban environmental conditions. Comments on *Arthopyrenia platypyrenia*, *Coenogonium tavaresianum*, *Gyalecta liguriensis*, *Lecania cyrtellina*, *Lecanographa amylacea*, *Micarea misella*, *Porina borreri*, and *Waynea stoechadiana* are given.

Keywords

Biodiversity, Botanic Garden of Pisa, Epiphytic lichens, Species conservation, Tuscany

Introduction

Botanical gardens are exceptional reservoirs of biodiversity, hosting not only plants intentionally cultivated and conserved but also a wide range of other organisms (e.g., lichens, fungi, bryophytes), which complement to the ecological complexity and richness of these specific environments (Ravera et al. 1999; Aptroot and Honegger 2006). Often located in town centres, they play a vital role as cultural and ecological hubs, serving as green refuges that mitigate urban heat and provide crucial climate-regulating benefits (Blackmore and Oldfield 2017; Cannon and Kua 2017; Primack et al. 2021; D'Antraccoli et al. 2023a). Botanical gardens support a variety of trees, including rare species (Jackson et al. 2001; Stevens 2007), providing a wide range of physical and chemical properties, which at once, create habitats that encourage the growth of epiphytic lichens.

Italy played a pivotal role in the establishment of botanical gardens, with its rich tradition of medicinal plant cultivation in monasteries and medical schools evolving into more systematic physic gardens during the 16th Century. According to Chiarugi (1953), Pisa (1543), Padua (1545, July), and Florence (1545, December) pioneered this movement, soon followed by significant botanical gardens in Bologna, Palermo, Naples, Rome, and other cities. These early academic institutions became essential centres for scientific study and the cultivation of medicinal plants, advancing medicine, botany, and global plant exchange, and reflecting Italy's leadership in botanical innovation during the Renaissance (Spencer and Cross 2017). While lichens are not typically a central focus in botanical gardens, historical records reveal occasional documentation of their presence. For example, notable specimens from the Botanic Garden of Pisa, currently preserved in the Herbarium of the University of Trieste (Martellos et al. 2023) and the Herbarium of the University of Pisa (see also Roma-Marzio et al. 2020, 2023 for details on digitized specimens) date back to 1862 (*Arthonia galactites* (DC.) Dufour collected by P. Savi and O. Beccari [PI067228, TSB25884]), 1882 (*Alyxoria varia* (Pers.) Ertz & Tehler [PI067229, TSB25514] and *Lecanora horiza* (Ach.) Linds. [TSB25512, TSB25513] collected by G. Arcangeli) and 1883 (*Alyxoria varia* [TSB25535, TSB25536] collected by A. Mori), offer valuable insights into the diversity that was present there in the past. Another herbarium specimen collected in that period in 1882 by G. Arcangeli refers to *Lecanora subfusca* (L.) Ach. var. *diffusa* Arcang. [PI067226, PI067227], a variety described from the Botanic Garden of Pisa, which grew on a ca. 100-year-old *Ginkgo biloba* L., and was also included in a series of exsiccata (Baglietto, Cesati & De Notaris, Erb. Critt. Ital. Ser. II, no. 1267). Early noteworthy observation of lichens was also made in the Botanical Garden of Florence by Cengia-Sambo in 1928, who reported the presence of an unidentified *Lecanora* species growing on the leaves of a 14-year-old *Syagrus coronata* (Mart.) Becc. cultivated in a warm and humid greenhouse (Cengia-Sambo 1928). In recent years, the diversity of lichens in botanical gardens across Italy has received increasing attention. Some studies have explored urban environments, such as the Botanical Garden of Rome, Lazio (Bartoli 1990; Ravera et al. 1999, 2003), as well as more natural sites as the Botanical Garden of the Apuan Alps "Pellegrini-Ansaldi" in Tuscany (Loppi and Putortì 2001) and the Garden of the Apennine Flora in Capracotta, Molise (Genovesi and Ravera 2014).

The Botanic Garden and Museum of the University of Pisa (hereafter Botanic Garden of Pisa) currently hosts more than 2,000 species in cultivation, grouped in about 30 collections (D'Antraccoli et al. 2024). The localization and the metadata associated with each plant specimen are accessible through the public version of the botanic garden's plant documentation system, U-plant DISCOVER (https://uplantdiscover.sma.unipi.it/). One of the most representative collections of the botanic garden is the Arboretum, consisting of about 200 species in cultivation (D'Antraccoli et al. 2023a). The oldest trees are a specimen of *Ginkgo biloba* L. and one of *Magnolia grandiflora* L., both planted in 1787 by Giorgio Santi (Savi 1828). The garden also hosts other noteworthy trees, including specimens of *Myrtus communis* L. and *Platanus hispanica* Mill. ex Münchh. (both over 200 years old), as well as specimens of *Araucaria bidwillii* Hook., *Chamaerops humilis* L., *Cinnamomum camphora* (L.) J.Presl, *Jubaea chilensis* (Molina) Baill., *Quercus virginiana* Mill., *Taxus baccata* L., *Tilia platyphyllos* Scop., *Washingtonia filifera* (Gloner ex Kerch., Burv., Pynaert, Rodigas & Hull) de Bary, and *Wisteria sinensis* (Sims) DC. These trees, introduced during the 19th century, range from 100 to 200 years (D'Antraccoli et al. 2022).

The aim of this study is to explore the epiphytic lichen diversity in the Botanic Garden of Pisa, to uncover the hidden biodiversity of botanical gardens in terms of non-target organisms. No published studies have specifically addressed the lichen biota in the Botanic Garden of Pisa, aside from the historical herbarium specimens mentioned earlier. By investigating this overlooked aspect, we also aim to contribute new and interesting data on the distribution of lichens in Tuscany.

Materials and methods

Study area

The Botanic Garden of Pisa extends within the urban city centre of Pisa, Italy (43.719966°N, 10.396161°E, alt. 5 m a.s.l.) for about 25,000 m^2, which are divided into seven sectors (Fig. 1), including a complex of greenhouses. The climate of the area

Figure 1. Planimetry of the Botanic Garden and Museum of the University of Pisa and its subdivision in sectors (from D'Antraccoli et al. 2023a, modified).

is characterized by mean annual temperature 15.2 °C, monthly mean 7.2 °C in the coldest month (January) and 24.4 °C in the hottest month (August). Rainfall totals 880 mm per year, with a minimum in summer (July: 29 mm) and a maximum in autumn (November: 144 mm) (LaMMA Consortium, Pisa climatology 1991–2020). According to the Köppen-Geiger climate classification, the region features a warm temperate climate with hot, dry summers (Kottek et al. 2006).

Data collection

Epiphytic lichens were surveyed during 2023 in the study area across more than 100 trees representing 61 different taxa. The trees were carefully selected to capture the full range of substrate variability, enabling comprehensive data collection on epiphytic lichen diversity. Lichens were identified based on their morphological, anatomical, and chemical characteristics by standard methods used in lichenology (Wirth et al. 2013). Relevant samples collected are deposited in the herbarium of the University of Pisa (PI) and in the herbarium of the Plant Science and Biodiversity Centre, Slovak Academy of Sciences (SAV), Slovakia. The distribution of new or confirmed species for Tuscany was discussed according to the distribution data available from Nimis (1993, 2024) and recently published papers.

Results

A total of 57 epiphytic lichen taxa and one non-lichenized fungus (Table 1), belonging to 53 species and subspecies within 40 genera were recorded.

Table 1. The list of lichens and non-lichenized fungi recorded on the trees of the Botanic Garden of Pisa, and their IUCN Red List category in Italy (Nascimbene et al. 2013). Species recorded only from Botanic Garden of Pisa and/or new for Tuscany are marked with asterisk (*). Abbreviations: DD = Data Deficient; LC = Least Concern; NT = Near Threatened; VU = Vulnerable. [n] = species tolerant to eutrophication (Nimis 2024).

Recorded taxon	Substrate	IUCN
Agonimia opuntiella (Buschardt & Poelt) Vězda	*Liriodendron tulipifera* L.	LC
Alyxoria varia (Pers.) Ertz & Tehler	*Acer oblongum* Wall. ex DC., *Ginkgo biloba* L., *Phillyrea angustifolia* L., *Pittosporum tobira* (Thunb.) W.T.Aiton	
[n]*Amandinea punctata* (Hoffm.) Coppins & Scheid.	*Gleditsia triacanthos* L., *Jubaea chilensis* (Molina) Baill., *Melia azedarach* L., *Pinus halepensis* Mill.	
Arthonia radiata (Pers.) Ach.	*Sorbus aria* (L.) Crantz.	
**Arthopyrenia platypyrenia* (Nyl.) Arnold	*Pittosporum tobira* (Thunb.) W.T.Aiton	
[n]*Candelaria concolor* (Dicks.) Stein	*Aesculus pavia* L., ×*Chitalpa tashkentensis* T.S.Elias & Wisura, *Cornus sanguinea* L., *Cotinus coggygria* Scop., *Diospyros lotus* L., *Gymnocladus dioicus* (L.) K.Koch., *Lagerstroemia indica* L., *Larix kaempferi* (Lamb.) Carrière, *Melia azedarach* L., *Phillyrea angustifolia* L., *Pittosporum tobira* (Thunb.) W.T.Aiton, *Pseudocydonia sinensis* (Dum.Cours.) C.K.Schneid., *Sequoia sempervirens* (D.Don) Endl., *Taxus baccata* L., *Vitex agnus-castus* L.	

Recorded taxon	Substrate	IUCN
Catapyrenium psoromoides (Borrer) R.Sant.	*Pinus halepensis* Mill.	NT
[n]*Catillaria nigroclavata* (Nyl.) J.Steiner	*Laburnum alpinum* (Mill.) Brecht. & J.Presl	
[n]*Cerothallia luteoalba* (Turner) Arup, Frödén & Søchting	*Catalpa bungei* C.A.Mey.	DD
Chrysothrix candelaris (L.) J.R.Laundon	*Arbutus unedo* L., *Gleditsia triacanthos* L., *Pyrus communis* L.	
Cladonia sp.	*Melia azedarach* L.	
**Coenogonium tavaresianum* (Vězda) Lücking, Aptroot & Sipman	*Calocedrus decurrens* (Torr.) Florin	VU
Dendrographa decolorans (Sm.) Ertz & Tehler	*Acer oblongum* Wall. ex DC., *Aesculus carnea* J.Zeyh., *A. pavia* L., *Butia capitata* (Mart.) Becc., *Calocedrus decurrens* (Torr.) Florin, *Camellia* sp., *Carya illinoinensis* (Wangenh.) K.Koch, *Citrus ×aurantium* L., *Cornus sanguinea* L., *Diospyros lotus* L., *Fraxinus excelsior* L., *Ginkgo biloba* L., *Gleditsia triacanthos* L., *Liriodendron tulipifera* L., *Magnolia grandiflora* L., *Phillyrea angustifolia* L., *Pyrus communis* L., *Quercus castaneifolia* C.A.Mey, *Q. virginiana* Mill., *Vitex agnus-castus* L.	
[n]*Diploicia canescens* (Dicks.) A.Massal.	*Carya illinoinensis* (Wangenh.) K.Koch, *Ginkgo biloba* L., *Pinus halepensis* Mill., *P. halepensis* Mill. subsp. *brutia* (Ten.) Holmboe, *Quercus virginiana* Mill.	
Evernia prunastri (L.) Ach.	*×Chitalpa tashkentensis* T.S.Elias & Wisura	
Flavoparmelia caperata (L.) Hale	*Arbutus unedo* L., *×Chitalpa tashkentensis* T.S.Elias & Wisura, *Cotinus coggygria* Scop., *Gleditsia triacanthos* L., *Jubaea chilensis* (Molina) Baill., *Lagerstroemia indica* L., *Larix kaempferi* (Lamb.) Carrière, *Liriodendron tulipifera* L., *Melia azedarach* L., *Prunus avium* L., *Pyrus communis* L., *Vitex agnus-castus* L.	
Flavoparmelia soredians (Nyl.) Hale	*Diospyros lotus* L., *Melia azedarach* L.	
Gyalecta liguriensis (Vězda) Vězda	*Magnolia grandiflora* L., *Salix eleagnos* Scop.	LC
[n]*Hyperphyscia adglutinata* (Flörke) H.Mayrhofer & Poelt	*Abies alba* Mill., *Acer campestre* L., *A. oblongum* Wall. ex DC., *Aesculus carnea* J.Zeyh., *A. pavia* L., *Butia capitata* (Mart.) Becc., *Calocedrus decurrens* (Torr.) Florin, *Camellia japonica* L. 'Eloisa Borrini', *C. japonica* L. 'Pomponia semiplena', *C. japonica* L. 'Tedeum', *Carya illinoinensis* (Wangenh.) K.Koch, *Catalpa* sp., *C. bungei* C.A.Mey., *×Chitalpa tashkentensis* T.S.Elias & Wisura, *Cinnamomum camphora* (L.) J.Presl, *Cornus sanguinea* L., *Corylus avellana* L., *Cotinus coggygria* Scop., *Crataegus rhipidophylla* Gand., *Cydonia oblonga* Mill., *Diospyros lotus* L., *Fraxinus excelsior* L., *Ginkgo biloba* L., *Gymnocladus dioicus* (L.) K.Koch., *Lagerstroemia indica* L., *Larix kaempferi* (Lamb.) Carrière, *Melia azedarach* L., *Olea europaea* L. subsp. *europaea*, *Phillyrea angustifolia* L., *Pinus halepensis* Mill. subsp. *brutia* (Ten.) Holmboe, *P. nigra* J.F.Arnold subsp. *nigra*, *P. pinea* L., *Pseudocydonia sinensis* (Dum.Cours.) C.K.Schneid., *Pyrus communis* L., *Quercus castaneifolia* C.A.Mey, *Taxus baccata* L., *Ulmus laevis* Pall., *Viburnum tinus* L., *Vitex agnus-castus* L.	
Lecania cyrtella (Ach.) Th.Fr.	*Pinus nigra* J.F.Arnold subsp. *nigra*	
**Lecania cyrtellina* (Nyl.) Sandst.	*Jubaea chilensis* (Molina) Baill.	
Lecania naegelii (Hepp.) Diederich & van den Boom	*×Chitalpa tashkentensis* T.S.Elias & Wisura, *Phillyrea angustifolia* L., *Vitex agnus-castus* L.	
Lecanographa amylacea (Pers.) Egea & Torrente	*Acer oblongum* Wall. ex DC., *Aesculus pavia* L., *Catalpa bungei* C.A.Mey., *Cedrus brevifolia* (Hook.f.) Elwes & A.Henry, *Cinnamomum camphora* (L.) J.Presl, *Diospyros lotus* L., *Ginkgo biloba* L., *Phillyrea angustifolia* L., *Quercus virginiana* Mill.	
Lecanora argentata (Ach.) Malme	*Vitex agnus-castus* L.	

Recorded taxon	Substrate	IUCN
[n]*Lecanora chlarotera* Nyl. subsp. *chlarotera*	*Camellia japonica* L. 'Pomponia semiplena', ×*Chitalpa tashkentensis* T.S.Elias & Wisura, *Vitex agnus-castus* L.	
Lecanora expallens Ach.	*Aesculus pavia* L., ×*Chitalpa tashkentensis* T.S.Elias & Wisura, *Melia azedarach* L., *Quercus virginiana* Mill.	
Lecanora strobilina (Spreng.) Kieff.	*Melia azedarach* L.	
[n]*Lecidella elaeochroma* (Ach.) M.Choisy var. *elaeochroma* f. *elaeochroma*	*Aesculus carnea* J.Zeyh., *A. pavia* L., ×*Chitalpa tashkentensis* T.S.Elias & Wisura, *Melia azedarach* L., *Phillyrea angustifolia* L., *Pinus halepensis* Mill., *Pyrus communis* L., *Sorbus aria* (L.) Crantz., *Vitex agnus-castus* L.	
Lepraria sp.	*Acer campestre* L., *A. monspessulanum* L., *Aesculus carnea* J.Zeyh., *Arbutus unedo* L., *Carya illinoinensis* (Wangenh.) K.Koch, *Cycas revoluta* Thunb., *Diospyros lotus* L., *Fraxinus excelsior* L., *Metasequoia glyptostroboides* Hu & W.C.Cheng, *Olea europaea* L. subsp. *europaea*, *Pyrus communis* L.	
Leprocaulon quisquiliare (Leers) M.Choisy	*Acer campestre* L., *A. monspessulanum* L., *Arbutus unedo* L., *Calocedrus decurrens* (Torr.) Florin, *Camellia japonica* L. 'Tedeum', *Carya illinoinensis* (Wangenh.) K.Koch, *Catalpa* sp., *Cinnamomum camphora* (L.) J.Presl, *Cycas revoluta* Thunb., *Diospyros lotus* L., *Fraxinus excelsior* L., *Ginkgo biloba* L., *Gymnocladus* dioicus (L.) K.Koch., *Liriodendron tulipifera* L., *Metasequoia glyptostroboides* Hu & W.C.Cheng, *Olea europaea* L. subsp. *europaea*, *Phytolacca dioica* L., *Prunus avium* L., *Pyrus communis* L., *Quercus virginiana* Mill., *Styphnolobium japonicum* (L.) Schott	
Melanelixia subaurifera (Nyl.) O.Blanco, A.Crespo, Divakar, Essl., D.Hawksw. & Lumbsch	×*Chitalpa tashkentensis* T.S.Elias & Wisura	
Micarea adnata Coppins	*Melia azedarach* L.	DD
Micarea misella (Nyl.) Hedl.	*Jubaea chilensis* (Molina) Baill.	
Micarea prasina Fr.	*Lagerstroemia indica* L., *Pinus nigra* J.F.Arnold subsp. *nigra*	
Normandina pulchella (Borrer) Nyl.	*Phillyrea angustifolia* L.	
Opegrapha sp.	*Pittosporum tobira* (Thunb.) W.T.Aiton	
Opegrapha niveoatra (Borrer) J.R.Laundon	*Ginkgo biloba* L.	
Opegrapha vulgata (Ach.) Ach.	*Ulmus laevis* Pall.	
Parmotrema perlatum (Huds.) M.Choisy	*Melia azedarach* L., *Prunus avium* L., *Pyrus communis* L.	
Pertusaria heterochroa (Müll.Arg.) Erichsen	*Melia azedarach* L.	
Pertusaria hymenea (Ach.) Schaer.	*Vitex agnus-castus* L.	
Phaeophyscia sp.	*Pittosporum tobira* (Thunb.) W.T.Aiton	
[n]*Phaeophyscia hirsuta* (Mereschk.) Essl.	*Acer monspessulanum* L., *Cornus sanguinea* L.	
[n]*Phaeophyscia orbicularis* (Neck.) Moberg	*Acer campestre* L., *Camellia japonica* L. 'Pomponia semiplena', *Cornus sanguinea* L., *Cotinus coggygria* Scop., *Metasequoia glyptostroboides* Hu & W.C.Cheng	
[n]*Physcia adscendens* H.Olivier	*Acer campestre* L., *Aesculus carnea* J.Zeyh., *A. pavia* L., *Arbutus unedo* L., *Carya illinoinensis* (Wangenh.) K.Koch, ×*Chitalpa tashkentensis* T.S.Elias & Wisura, *Cinnamomum camphora* (L.) J.Presl, *Cornus sanguinea* L., *Cotinus coggygria* Scop., *Crataegus rhipidophylla* Gand., *Cydonia oblonga* Mill., *Diospyros lotus* L., *Gymnocladus dioicus* (L.) K.Koch., *Lagerstroemia indica* L., *Larix kaempferi* (Lamb.) Carrière, *Metasequoia glyptostroboides* Hu & W.C.Cheng, *Olea europaea* L. subsp. *europaea*, *Phillyrea angustifolia* L., *Pinus nigra* J.F.Arnold subsp. *nigra*, *P. pinea* L., *Pseudocydonia sinensis* (Dum.Cours.) C.K.Schneid., *Pyrus communis* L., *Sorbus aria* (L.) Crantz., *Taxus baccata* L., *Ulmus laevis* Pall., *Vitex agnus-castus* L., *Wisteria sinensis* (Sims) DC.	
Physcia clementei (Turner) Lynge	×*Chitalpa tashkentensis* T.S.Elias & Wisura	
[n]*Physcia tenella* (Scop.) DC.	*Catalpa* sp., *Cornus sanguinea* L., *Phillyrea angustifolia* L., *Pinus halepensis* Mill.	

Recorded taxon	Substrate	IUCN
[n]*Physciella chloantha* (Ach.) Essl.	*Camellia japonica* L. 'Tedeum', *Carya illinoinensis* (Wangenh.) K.Koch, *Cotinus coggygria* Scop., *Diospyros lotus* L., *Ginkgo biloba* L., *Liriodendron tulipifera* L., *Phytolacca dioica* L.	
Physconia sp.	*Liriodendron tulipifera* L.	
[n]*Physconia grisea* (Lam.) Poelt subsp. *grisea*	*Carya illinoinensis* (Wangenh.) K.Koch, *Metasequoia glyptostroboides* Hu & W.C.Cheng, *Pyrus communis* L.	
Porina aenea (Wallr.) Zahlbr.	*Styphnolobium japonicum* (L.) Schott, *Ulmus laevis* Pall.	
Porina borreri (Trevis.) D.Hawksw. & P.James	*Aesculus pavia* L., *Magnolia grandiflora* L., *Vitex agnus-castus* L.	
Punctelia borreri (Sm.) Krog	*Liriodendron tulipifera* L.	
Punctelia subrudecta (Nyl.) Krog	*Aesculus pavia* L., *Aesculus carnea* J.Zeyh., *Carya illinoinensis* (Wangenh.) K.Koch, ×*Chitalpa tashkentensis* T.S.Elias & Wisura, *Liriodendron tulipifera* L., *Olea europaea* L. subsp. *europaea*, *Phillyrea angustifolia* L., *Phytolacca dioica* L., *Pseudocydonia sinensis* (Dum.Cours.) C.K.Schneid., *Pyrus communis* L., *Ulmus laevis* Pall.	
Pyrenula chlorospila Arnold	*Aesculus carnea* J.Zeyh., *A. pavia* L., *Corylus avellana* L., *Phillyrea angustifolia* L., *Vitex agnus-castus* L.	
Strangospora pinicola (A.Massal.) Körb.	*Jubaea chilensis* (Molina) Baill.	VU
Waynea stoechadiana (Abbassi Maaf & Cl.Roux) Cl.Roux & P.Clerc	*Acer campestre* L., *Pinus nigra* J.F.Arnold subsp. *nigra*	VU
[n]*Xanthoria parietina* (L.) Th.Fr.	*Aesculus carnea* J.Zeyh., *A. pavia* L., *Camellia japonica* L. '*Pomponia semiplena*', *Carya illinoinensis* (Wangenh.) K.Koch, ×*Chitalpa tashkentensis* T.S.Elias & Wisura, *Crataegus rhipidophylla* Gand., *Cydonia oblonga* Mill., *Fraxinus excelsior* L., *Laburnum alpinum* (Mill.) Brecht. & J.Presl, *Larix kaempferi* (Lamb.) Carrière, *Metasequoia glyptostroboides* Hu & W.C.Cheng, *Phytolacca dioica* L., *Pyrus communis* L., *Ulmus laevis* Pall., *Vitex agnus-castus* L.	

Discussion

Epiphytic lichens were surveyed in both indoor and outdoor environments of the Botanic Garden. However, so far, no lichens were found on trees cultivated in greenhouses, despite several of them being examined carefully (namely *Brachychiton acerifolius* (A.Cunn. ex G.Don) F.Muell., *B. discolor* F.Muell., *B. rupestris* (T.Mitch. ex Lindl) K.Schum., *Cycas taiwaniana* Carruth., *C. circinalis* L., *Ficus elastica* Roxb. ex Hornem., *Strelizia nicolai* Regel & K.Koch, *Sterculia balanghas* L.). Only a colonization by green algae was noticed on some of the barks (especially on *Cycas taiwaniana* and *Ficus elastica*). All recorded lichens were found in outdoor conditions with varying levels of colonization across different trees. Sparse lichen growth, with thalli appearing sporadically or in minimal coverage, was observed on trees of the genera *Camellia*, *Cedrus*, *Citrus*, *Sequoia*, *Viburnum*, and *Wisteria*. No lichen colonization was observed on the bark of *Araucaria bidwillii*, a tree that has stood in the garden for 152 years. In contrast, species like *Aesculus pavia*, ×*Chitalpa tashkentensis*, *Melia azedarach*, *Phillyrea angustifolia*, *Pyrus communis*, and *Vitex agnus-castus* exhibited a high degree of colonization, particularly in terms of diversity, with more than ten lichen species identified from the individual trees.

According to the red list of epiphytic lichens of Italy (Nascimbene et al. 2013), three lichen species are considered Vulnerable, one is included in the category Near Threatened,

two in Least Concern and other two in Data Deficient IUCN categories (Table 1). Two species, *Arthopyrenia platypyrenia* (Nyl.) Arnold and *Coenogonium tavaresianum* (Vězda) Lücking, Aptroot & Sipman, are newly recorded for the lichen biota of Tuscany, and *Lecania cyrtellina* (Nyl.) Sandst. is so far known only from the study area (Ravera et al. 2024). Additionally, the record of *Arthopyrenia platypyrenia* is the second for Italy.

The lichen biota in the Botanic Garden is mainly composed by acidophilous/oligotrophic species (about 70%), overall reflecting the availability of acidic (bark) substrates. Nevertheless, the wide distribution of species tolerant to eutrophication, or even enhanced by the deposition of dust and nitrogen compounds (such as *Hyperphyscia adglutinata*, *Physcia adscendens*, *Candelaria concolor*, and *Xanthoria parietina*, early colonizers of eutrophicated substrates), well reflect the influence of urban atmospheric conditions, especially in more open conditions. This phenomenon is particularly evident on the bark of conifers, which in their natural environment are generally colonized by acidophilous epiphytes, but in the Botanic Garden of Pisa are more often colonized by nitrophilous lichens. Lichen colonization is influenced by various interacting factors, such as light availability, relative humidity, bark chemistry, water-holding capacity, health status of the substrate and environmental pollution (Hauck 2005; Loppi and Baragatti 2011; Ellis 2012). Some of them are directly shaped by the characteristics of the individual tree hosting the lichen, as well as the composition of the surrounding vegetation (Petersson et al. 2022 and references therein). Consequently, a condition with a greater diversity of tree species and structural features (such as in even aged forests) often supports higher lichen species richness (Petersson et al. 2022). The same could apply also to botanical gardens. In general, the diverse range of trees, with their physical and chemical properties, creates various habitats that support the growth of epiphytic lichens thriving on their surfaces (e.g. Käffer et al. 2016). In fact, there is evidence that the lichen biota in a botanical garden is proportionally richer than that of the surrounding environment, especially in urban contexts (Aptroot and Honegger 2006; Wilkie 2020).

On the other hand, along with nitrophilous species commonly found in urban areas, the Botanic Garden of Pisa hosts several species, whose presence is typically associated with more natural environments. Among them, *Coenogonium tavaresianum*, *Gyalecta liguriensis*, *Lecanographa amylacea*, and *Porina borreri* are also recognized as indicators of undisturbed forests and ancient woodlands (Nimis 2024) and were observed on some of the garden's monumental trees, including *Ginkgo biloba*, *Magnolia grandiflora*, *Cinnamomum camphora*, and *Quercus virginiana.* Additional species like *Catapyrenium psoromoides*, *Micarea adnata*, *M. misella*, *M. prasina*, *Opegrapha niveoatra*, *Porina aenea*, *Pyrenula chlorospila*, and *Waynea stoechadiana* exhibit affinities for natural and semi-natural habitats (Nimis 2024). Notably, some of them, including *C. tavaresianum*, *G. liguriensis*, *L. amylacea*, *M. prasina*, *O. niveoatra*, and *W. stoechadiana*, have also been recorded in the Botanical Garden of Rome (Ravera et al. 1999), highlighting the role of botanical gardens as alternative habitats for species with specific ecological demands. Botanical gardens in city centres serve as vital green islands, offering a sanctuary for diverse plant and fungal species amidst urban landscapes. Their importance as refugia for biodiversity can be also exemplified by the New Botanical Garden of the University Zürich: despite a relatively small area (53,000 m^2), it hosts approximately 10% of all lichen species recorded in Switzerland (Aptroot and Honegger 2006).

In the following section there are specific notes on several species of concern found within the Botanic Garden of Pisa.

Arthopyrenia platypyrenia

This species is an inconspicuous non-lichenised fungus with endosubstratic thallus (Nimis 2024). On the studied trees, it appears only as a discoloration of the bark. It has rounded black perithecia with characteristic pluriseptate ascospores (in collected samples mostly 5–6-septate in size 26.2–28.7 × 8.7–10 µm), with clear constriction at each septum and a 2.5 µm thick gelatinous sheath. The distribution and ecology of this species is poorly understood, with only a few reported occurrences across Europe. It was found especially on the bark of *Hedera* sp. (Coppins and Orange 2009) and *Fraxinus ornus* L. (Consortium of Lichen Herbaria 2024). The only previous Italian record refers to the samples found in Calabria on *Hedera helix* L. climbing on the base of *Populus nigra* L. in humid conditions (Puntillo 1996). In the Botanic Garden of Pisa, it colonizes the bark of *Pittosporum tobira*. This species is recorded here for the first time in Tuscany and for the second time in Italy.

Coenogonium tavaresianum

This species is recorded here for the first time in Tuscany. The olive-green, finely granulose to verrucose thalli colonize the bark of *Calocedrus decurrens* quite abundantly. The species features small biatorine apothecia with pale discs and dark margins, which are constricted at the base. Another distinguishing feature is the presence of small, 1-septate ascospores, mostly measuring 12.5 × 2.5–3 µm in collected samples. The distribution of species in Italy is primarily confined to humid woodlands along the Tyrrhenian coast (Nimis 2024), but it has also been reported from more urban environments such as the Botanical Garden of Rome (Ravera et al. 1999). It is included in the red list of epiphytic lichens of Italy as vulnerable and likely experiencing a declining trend (Nascimbene et al. 2013).

Gyalecta liguriensis

This crustose species is characterized by muriform and distinctively lemon shaped ascospores with pointed apices. It usually grows on ancient trees in coastal areas (Alvarez Andrés and López de Silanes 2002; Nimis 2024). In the study area, a few thalli were recorded on more than 230-year-old tree *Magnolia grandiflora* and younger tree *Salix eleagnos*. However, the latter is no longer cultivated in the garden, as the tree died in 2024.

Lecania cyrtellina

This is a crustose epiphytic lichen, that primarily grows on the basic bark of deciduous trees such as *Acer*, *Fraxinus*, *Ulmus*, and *Alnus* (Reese Næsborg 2008). In the Botanic Garden of Pisa, it grows on more than 130 years old Chilean wine palm *Jubaea chilensis*. The lichen features a pale thallus and clustered small lecanorine apothecia (0.1–0.3 mm in diam.) with thin and disappearing thalline margin. The ascospores are

mostly simple, narrow and short (9 × 2.5 µm in collected samples), unlike the other related species *L. cyrtella* (Reese Næsborg 2008). Most Italian records of *L. cyrtellina* are from recent years, as the species was not consistently distinguished from *L. cyrtella* in the past. The Botanic Garden of Pisa is currently the only known locality for this species in Tuscany, as reported by Ravera et al. (2024).

Lecanographa amylacea

This species shows strong morphological dimorphism depending on the photobiont type present in the lichen. The sorediate morphotype is characterized by the presence of *Trebouxia* photobionts, while the non-sorediate fertile morphotype contains *Trentepohlia* as a photobiont (Ertz et al. 2018). In the Botanic Garden of Pisa, a photomorph with *Trentepohlia* sp. was observed on the bark of various trees (e.g., *Acer*, *Aesculus*, *Catalpa*, *Cedrus*, *Cinnamomum*, *Diospyros*, *Ginkgo*, *Phillyrea*, and *Quercus*), exhibiting white farinose thallus with black, densely white-pruinose apothecia. In Italy, it is considered as a rare species (Nimis 2024) linked mostly to old trees in ancient woodlands and urban parks or old olive groves (Ravera et al. 2021). This is the second locality reported in Tuscany, as it had previously been found in another location between Pietrapiana and Saltino (Nimis 1993).

Micarea misella

This species shows a thallus of small, pale green-grey granules and black apothecia (proper exciple K+ violet, small simple ascospores). It was found on old tree *Jubaea chilensis*. Its occurrence in Italy is more confined to the area of Alps, but it is also distributed along the Apennines (Nimis 2024). In Tuscany, it was found for the first time in 2016 in Abetone (Ravera et al. 2016). Here we present the second record for Tuscany.

Porina borreri

This is a crustose lichen producing black prominent perithecia with multiseptate ascospores. The apex of asci is mostly truncate with a refractive ring structure. This species is mostly recorded in old woodlands with higher humidity (Nimis 2024). Only one previous record has been published from Tuscany, referring to a locality close to Volterra (Nimis 1993).

Waynea stoechadiana

This is a sorediate squamulose lichen, which initially may resemble *Hypocenomyce scalaris* (Ach.) M. Choisy, but differs in several key characteristics, such as the chemical reactions of thallus (C-, KC-) and the type of ascospores (mostly 1-septate, longer and narrower). The species belongs to Mediterranean elements. It is considered as a rare species of conservation concern, with IUCN status Vulnerable (Nascimbene et

al. 2013; Nimis 2024). It is mainly confined to warm, humid conditions along the Tyrrhenian coast (Nimis 2024). In Tuscany, the occurrence records are quite scarce (see Nimis 1993, 2024), however, other localities with rich populations of this species have been documented by recently collected material between Punta Ala and Follonica (Italy, Tuscany, Punta Ala: the beach Cala Violina (42.857027°N, 10.774941°E), *Quercus ilex* wood around picnic zone, on *Q. ilex*, 20 m, 28 April 2023, *L. Paoli, Z. Fačkovcová, A. Bérešová* SAV0017540, SAV0018119, SAV0018120).

Conclusion

Botanical gardens can contribute to biodiversity conservation not only for taxa in cultivation (see for instance D'Antraccoli et al. 2023b), but also in the case of non-target spontaneously growing organisms such as lichens, which can benefit indirectly from habitats and conditions provided by botanical gardens, such as in urban environments. Although lichens are not usually a primary focus in botanical gardens, these spaces can serve as important refuges for their diversity. Indeed, the lichen biota of the Botanic Garden of Pisa includes also rare species according to the red list of epiphytic lichens of Italy (Nascimbene et al. 2013), and for three taxa, this is currently the only known locality in Tuscany. Lichen colonization (especially by acidophilous/oligotrophic species) well reflects the richness of tree substrates, while the distribution of nitrogen-tolerant lichens is likely associated with urban environmental conditions.

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References

Alvarez Andrés J, López de Silanes ME (2002) The genus *Gyalecta* (Gyalectales, Ascomycotina) in the Iberian Peninsula. Nova Hedwigia 74: 257–273. https://doi.org/10.1127/0029-5035/2002/0074-0257

Aptroot A, Honegger R (2006) Lichens in the New Botanical Garden of the University of Zürich, Switzerland. Botanica Helvetica 116: 135–148. https://doi.org/10.1007/BF02861093

Bartoli A (1990) I licheni della peschiera dei tritoni nell'Orto Botanico di Roma, Villa Corsini. Atti 85° Congresso S. B. I. Napoli, Giornale Botanico Italiano 124: 87. https://doi.org/10.1080/11263509009430654

Blackmore S, Oldfield S [Eds] (2017) Plant Conservation Science and Practice: the Role of Botanic Gardens (Ecology, Biodiversity and Conservation). Cambridge University Press, 1–395. https://doi.org/10.1017/9781316556726.003

Cannon CH, Kua CS (2017) Botanic gardens should lead the way to create a "Garden Earth" in the Anthropocene. Plant Diversity 39: 331–337. https://doi.org/10.1016/j.pld.2017.11.003

Cengia-Sambo M (1928) Un Lichene epifillo su una Palma di serra dell'Orto Botanico di Firenze. Nuovo Giornale Botanico Italiano (nuova serie) 35(2): 257–259.

Chiarugi A (1953) Le date di fondazione dei primi Orti Botanici del mondo. Giornale Botanico Italiano 60(4): 785–839. https://doi.org/10.1080/11263505309431548

Consortium of Lichen Herbaria (2024) Consortium of Lichen Herbaria. http//:lichenportal.org/portal/index.php [accessed 30 September 2024]

Coppins BJ, Orange A (2009) *Arthopyrenia*. In: Smith CW, Aptroot A, Coppins BJ, Fletcher A, Gilbert OL, James PW, Wolseley PA (Eds) The Lichens of Great Britain and Ireland. The British Lichen Society, Department of Botany, The Natural History Museum, London, United Kingdom, 171–176.

D'Antraccoli M, Remorini D, Tasca F, Cocchi L, Peruzzi L (2022) The monumental trees of the Botanic Garden of Pisa. In: Book of abstracts, Convegno Internazionale Alberi Monumentali - Palermo (Italy), 14–16 October 2022.

D'Antraccoli M, Weiger N, Cocchi L, Peruzzi L (2023a) The trees of the Pisa Botanic Garden under climate change scenarios: what are we walking into? Sustainability 15(5): 4585. https://doi.org/10.3390/su15054585

D'Antraccoli M, Carta A, Astuti G, Franzoni J, Giacò A, Tiburtini M, Pinzani L, Peruzzi L. (2023b) A comprehensive approach to improving endemic plant species research, conservation, and popularization. Journal of Zoological and Botanical Gardens 4(2): 490–506. https://doi.org/10.3390/jzbg4020036

D'Antraccoli M, Amadei L, Peruzzi L (2024) Le collezioni vegetali dell'Orto e Museo Botanico dell'Università di Pisa. In: AA. VV., Musei di Scienze Naturali e di Scienze Mediche. Il Rintocco del Campano, 74–83.

Ellis CJ (2012) Lichen epiphyte diversity: a species, community and trait-based review. Perspectives in Plant Ecology, Evolution and Systematics 14: 131–152. https://doi.org/10.1016/j.ppees.2011.10.001

Ertz D, Guzow-Krzemińska B, Thor G, Łubek A, Kukwa M (2018) Photobiont switching causes changes in the reproduction strategy and phenotypic dimorphism in the Arthoniomycetes. Scientific Reports 8: 4952. https://doi.org/10.1038/s41598-018-23219-3

Genovesi V, Ravera S (2014) Guida ai licheni del Giardino della Flora Appenninica di Capracotta. [ISBN 978-88-909741-0-6]

Hauck M (2005) Epiphytic lichen diversity on dead and dying conifers under different levels of atmospheric pollution. Environmental Pollution 135(1): 111–119. https://doi.org/10.1016/j.envpol.2004.09.021

Jackson PW, Bridge B, Dennis F, Leadlay E, Hobson C, Holland F, Pendry T, Skilton J, Sutherland L, Willison J, et al. (2001) An international review of the *ex situ* plant collections of the botanic gardens of the world: Reviewing the plant genetic resource collections of botanic gardens worldwide, as a contribution to decision V/26 on Access to Genetic Resources of the Conference of the Parties to the Convention on Biological Diversity—Part 1: Overview and analysis. Richmond, UK. Botanic Gardens Conservation International News 3: 22–33.

Käffer MI, Koch NM, De Martins SM, Vargas VMF (2016) Lichen community versus host tree bark texture in an urban environment in southern Brazil. Iheringia, Série Botânica 71(1): 49–54.

Kottek M, Grieser J, Beck C, Rudolf B, Rubel F (2006) World map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift 15: 259–263. https://doi.org/10.1127/0941-2948/2006/0130

Loppi S, Baragatti E (2011) Influence of the health status of pine trees on the diversity of epiphytic lichens. Nova Hedwigia 93: 201–210. https://doi.org/10.1127/0029-5035/2011/0093-0201

Loppi S, Putortì E (2001) I licheni epifiti dell'Orto Botanico delle Alpi Apuane. Informatore Botanico Italiano 33: 15–16.

Martellos S, Nimis PL, Conti M (2023) TSB Lichen Herbarium. Department of Biology, University of Trieste. Occurrence dataset. [accessed 29 November 2024]

Nascimbene J, Nimis PL, Ravera S (2013) Evaluating the conservation status of epiphytic lichens of Italy: A red list. Plant Biosystems 147(4): 898–904. https://doi.org/10.1080/11263504.2012.748101

Nimis PL (1993) The Lichens of Italy. An Annotated Catalogue. Museo Regionale di Scienze Naturali Torino, Monografie XII: 1–897.

Nimis PL (2024) ITALIC - The Information System on Italian Lichens. Version 8.0. University of Trieste, Department of Biology. https://dryades.units.it/italic [accessed 30 September 2024]

Petersson L, Lariviere D, Holmström E, Fritz Ö, Felton A (2022) Conifer tree species and age as drivers of epiphytic lichen communities in northern European production forests. The Lichenologist 54(3–4): 213–225. https://doi.org/10.1017/S0024282922000172

Primack RB, Ellwood ER, Gallinat AS, Miller-Rushing AJ (2021) The growing and vital role of botanical gardens in climate change research. New Phytologist 231: 917–932. https://doi.org/10.1111/nph.17410

Puntillo D (1996) I Licheni di Calabria. Museo Regionale di Scienze Naturali Torino, Monografie 22: 1–229.

Ravera S, Brezzi G, Massari G (1999) Contributo alla conoscenza dei licheni dell'area romana: la florula epifitica dell'Orto Botanico di Villa Corsini. Biologi Italiani 10: 37–43.

Ravera S, Munzi S, Roffilli R (2003) Contributo alla conoscenza dei licheni epifiti dell'area romana. Notiziario della Società Lichenologica Italiana 16: 77.

Ravera S, Cogoni A, Totti C, Aleffi M, Assini S, Caporale S, Fačkovcová Z, Filippino G, Gheza G, Olivieri N, Ottonello M, Paoli L, Poponessi S, Pišút I, Venanzon R (2016) Notulae to the Italian flora of algae, bryophytes, fungi and lichens: 2. Italian Botanist 1: 43–54. https://doi.org/10.3897/italianbotanist.2.10812

Ravera S, Puglisi M, Vizzini A, Aleffi A, Benesperi R, Bergamo Decarli G, Berta G, Bianchi E, Boccardo F, Briozzo I, Clericuzio M, Cogoni A, Croce A, Dagnino D, De Agostini A, De Giuseppe AB, Di Nuzzo L, Dovana F, Fačkovcová Z, Gheza G, Loppi S, Malíček J, Mariotti M, Nascimbene J, Nimis PL, Paoli L, Passalacqua NG, Plášek V, Poponessi S, Prosser F, Puntillo D, Puntillo M, Rovito S, Sguazzin F, Sicoli G, Tiburtini M, Tomaselli V, Turcato C, Vallese C (2021) Notulae to the Italian flora of algae, bryophytes, fungi and lichens: 11. Italian Botanist 11: 45–61. https://doi.org/10.3897/italianbotanist.11.64557

Ravera S, Vizzini A, Puglisi M, Totti C, Angiolini C, Azzella MM, Bacilliere G, Boccardo F, Bonini I, von Brackel W, Brusa G, Cavallaro V, Cancellieri L, Cannucci S, Cantonati M, De Giuseppe AB, Di Nuzzo L, Dovana F, Fanfarillo E, Fiaschi T, Filibeck G, Francesconi L, Gheza G, Giordani P, Guttová A, Hafellner J, Isocrono D, Malíček J, Mayrhofer H, Miraglia G, Nascimbene J, Nimis PL, Ongaro S, Pandeli G, Paoli L, Passalacqua NG, Pinault P, Pistocchi C, Potenza G, Prosser F, Puntillo D, Puntillo M, Rosati L, Sicoli G, Tiburtini M, Tretiach M, Zedda L (2024) Notulae to the Italian flora of algae, bryophytes, fungi and lichens: 17. Italian Botanist 17: 23–41. https://doi.org/10.3897/italianbotanist.17.123283

Reese Næsborg R (2008) Taxonomic revision of the *Lecania cyrtella* group based on molecular and morphological evidence. Mycologia 100(3): 397–416. https://doi.org/10.3852/07-080R

Roma-Marzio F, Amadei L, Dolci D, Maccioni S, Vangelisti R, Peruzzi L (2020) La digitalizzazione dell'Herbarium Horti Botanici Pisani: Stato dell'arte e prospettive future. Notiziario della Società Botanica Italiana 4(2): 181–182.

Roma-Marzio F, Maccioni S, Dolci D, Astuti G, Magrini N, Pierotti F, Vangelisti R, Amadei L, Peruzzi L (2023) Digitization of the historical Herbarium of Michele Guadagno at Pisa (PI-GUAD). PhytoKeys 234: 107–125. https://doi.org/10.3897/phytokeys.234.109464

Savi G (1828) Notizie per servire alla storia del Giardino e Museo della I. E R. Università di Pisa. Nistri (Ed), Pisa.

Spencer R, Cross R (2017) The origins of botanic gardens and their relation to plant science, with special reference to horticultural botany and cultivated plant taxonomy. Muelleria: An Australian Journal of Botany 35: 43–93. https://doi.org/10.5962/p.291985

Stevens AD (2007) Botanical gardens and their role in *ex situ* conservation and research. Phyton-Annales Rei Botanicae 46: 211–214.

Wilkie IC (2020) The lichens of Glasgow Botanic Gardens. The Glasgow Naturalist 27(3): 77–85. https://doi.org/10.37208/tgn27315

Wirth V, Hauck M, Schultz M (2013) Die Flechten Deutschlands. Ulmer, Stuttgart. 1–2: 1–1244.